Template for ISB Documentation of Stressors

A. General Information: Nutrient Loading, Eutrophication, Thresholds, Direct and Indirect Consequences

1. Name or Location of Example/Approach: Chesapeake Bay

2. Literature/Citations Used:

Kemp, W. M. and E. B. Goldman. 2008. Thresholds in the recovery of eutrophic coastal ecosystems. A synthesis of research and implications for management. Workshop Report, Scientific and Technical Advisory Committee to Chesapeake Bay Program. Maryland Sea Grant Publication UM-SG-TS-2008-01.

3. Reviewer(s): Ed Houde and Liz Canuel

B. Specific Questions:

1. What stressors are considered?

Nutrient Loading; nitrogen and phosphorus, and related factors

2. Are stressors categorized? If so, how?

Yes. Effects of high nutrient loads on ecosystem structure and function, especially in Chesapeake Bay, are highlighted. Threshold responses, interactions, and resistance to recovery are emphasized.

3. Are the relations between stressors and management objectives modeled, and if so, how?

The workshop addresses modeling and analytical approaches to forecast or predict how an estuarine ecosystem may recover (or not) from nutrient overloading. Straight-line trajectories of recovery in response to proportional reductions in nutrient loading often do not occur. Managers need to be aware of the potential non-linearities, the possibility of hysteresis, and other complex, unexpected behavior of estuarine ecosystems recovering from eutrophication.

4. If stressors are prioritized, describe the general approach.

5. How might this approach be relevant to Bay Delta?

The approaches that are described and advice provided in recommendations by this workshop are broadly relevant to the Bay Delta. While eutrophication is not presently a major problem, it is potentially a problem in the future. Moreover, the concept of threshold behavior, understanding the consequences of exceeding thresholds, and understanding time lags and non-linear responses of ecosystems to relaxation of stresses in general are addressed in this report and are relevant to the Bay Delta ecosystem.

6. Follow up regarding additional questions/literature review/etc?

Recommendations for research and management in this report are worth noting.

A long list of references on eutrophication, multiple stressors, recovery from eutrophication, threshold and non-linear responses, is included in the report.

Template for ISB Documentation of Stressors

A. General Information: Nutrients and Trace Elements

1. Name or Location of Example/Approach: Chesapeake Bay; large experimental ecosystems; population and community responses

2. Literature/Citations Used:

Breitburg, D. L., J. D. Sanders, C. C. Gilmour, R. W. Osman, G. F. Riedel, S. P. Seitzinger and K. G. Sellner. 1999. Variability in responses to nutrients and trace elements, and transmission of stressor effects through an estuarine food web. Limnology and Oceanography 44(3, pt 2):837-863.

3. Reviewer(s): Ed Houde

B. Specific Questions:

1. What stressors are considered?

The researchers conducted a comprehensive set of experiments in mesocosms to test whether responses of estuarine biological communities (microbes to fish and benthic invertebrates) could be predicted with respect to individual stressors (nutrients or a mixture of trace metals) or combinations of the stressors at various concentrations.

Nutrients: Nitrogen and Phosphorus (ambient and above ambient)

Trace Elements: Ni, Zn, Cd, As, Cu (control ambient and added concentrations)

2. Are stressors categorized? If so, how?

Yes, see above

3. Are the relations between stressors and management objectives modeled, and if so, how?

4. If stressors are prioritized, describe the general approach.

Four 1-month experiments were run in experimental ecosystems of varying biological complexity (trophic depth and breadth). The systems were intensively monitored to measure and interpret community-level responses. Results indicated that responses to trace metals were more variable and diffilcult to predict than responses to

nutrients. For some taxa, responses indicated that nutrients and trace metals interacted in complex ways. Trace elements may mask the response of biota to high nutrient loading in eutrophic estuaries.

5. How might this approach be relevant to Bay Delta?

The Delta is impacted by a complex suite of multiple stressors which could either increase or dampen variability in productivity at multiple trophic levels, depending on interactions among the stressors, presence (or not) of sensitive taxa, and background environmental conditions.

6. Follow up regarding additional questions/literature review/etc?

Several other relevant papers on a broad range of stressors in aquatic systems are found in:

Breitburg, D, S. Seitzinger and J. Sanders (editors). The effects of multiple stressors on freshwater and marine ecosystems. Limnology and Oceanography 44 (3, part 2):735-972.

Template for ISB Documentation of Stressors

A. General Information: Multiple Stressors - Interactions

1. Name or Location of Example/Approach:

2. Literature/Citations Used:

Breitburg, D.L. & G.F. Riedel (2005) Multiple stressors in Marine Systems. In: The Sciences of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder (eds.), Island Press, Washington DC.

3. Reviewer(s): Elizabeth Canuel

B. Specific Questions:

1. What stressors are considered?

Nutrient loading and overfishing: when overfishing reduces populations of herbivores or suspension feeders that consume primary producers, it potentially increases deleterious effects of nutrient loading.

- **Overfishing and nutrient enrichment may alter food web – may lead to greater fisheries production initially in oligotrophic systems.**

Trace metals and nutrients: interactions between trace elements and nutrients can alter patterns of spatial and temporal variability within marine systems

- **Trace elements can mask or reduce effects of high nutrient loadings**

2. Are stressors categorized? If so, how?

This paper provides conceptual model of unique patterns of stressor effects and the scales of how they impact ecosystems (e.g., chemical toxicity may be intense at local level but weak on wide scale while effects of global climate change are likely to be widely distributed).

Additive/synergistic stressors – the change caused at physiological or ecological by one stressor increases the severity or occurrence of effects of second stressors

Antagonistic (or less than additive) –stressors have overlapping effects or one stressor reduces the effects of other stressors

3. Are the relations between stressors and management objectives modeled, and if so, how?

4. If stressors are prioritized, describe the general approach.

5. How might this approach be relevant to Bay Delta?

- **Individual stressors fundamentally change the playing field upon which additional stressors act by selecting for tolerant species and by changing the abundance, distribution or interactions of structural species, predators, prey, parasites and hosts.**

- **Recovery period from a particular stress can extend beyond the period of exposure, influencing the response to subsequent stressors (e.g., this may be the case for legacy sediments and materials associated with these sediments).**

- **Effects of stressors can extend beyond spatial scale of stressor, increasing the potential for interactions with additional stressors.**

- **Over time, heritable adaptations that increase tolerance to one class of stressors can increase susceptibility to others (Meyer and DiGiulio (2003) Ecol Applic. 13: 490-503).**

6. Follow up regarding additional questions/literature review/etc?

Template for ISB Documentation of Stressors

A. General Information: **Nutrients, Hypoxia and Fisheries**

1. Name or Location of Example/Approach: Estuaries and Coastal Seas

2. Literature/Citations Used:

Breitburg, D. L., D. W. Hondorp, l. A. Davias and R. J. Diaz. 2009. Hypoxia, nitrogen, and fisheries: integrating effects across local and global landscapes. Annual Review of Marine Science 1:329-349.

3. Reviewer(s): Ed Houde

B. Specific Questions:

1. What stressors are considered?

Hypoxia, Nitrogen, Fishing.

The primary question addressed in this review is whether nutrient loading that often is associated with hypoxia in many coastal seas and estuaries is linked to fisheries landings (and by implication to fisheries productivity).

2. Are stressors categorized? If so, how?

Yes. Hypoxia in estuaries and coastal seas is a stress that often is a consequence of high nutrient loading and is hypothesized to adversely affect fisheries landings. Results of the review showed that there is a general association of increasing hypoxia with increased nutrient loading, but there are many exceptions that depend on basin morphometry, residence times, tides and other variables. Fisheries landings (per km^2) are positively related to nitrogen loading with a tendency to decline at the highest nitrogen loading levels. There was no significant relationship between fisheries landings per unit nitrogen loading and spatial extent of bottom-water hypoxia and not trends over time in this relationship - - a surprising outcome.

3. Are the relations between stressors and management objectives modeled, and if so, how?

In Chesapeake Bay and many estuaries where nutrient enrichment and eutrophication have been identified as a major problem, the danger to fisheries of increasing nutrient loading and hypoxia often is cited. This review showed that the generality of this hypothesized outcome is uncertain at best. Some estuaries did

have low fish landings under conditions of high nutrient loading and extensive hypoxia, but others did not show a releationship. Still, ome species of fish and invertebrates (especially benthic and demersal taxa) clearly were negatively impacted by hypoxia.

4. If stressors are prioritized, describe the general approach.

The authors tentatively concluded that the effect of hypoxia on fisheries landings essentially can't be separated from the effect of nitrogen loading level. The approach consisted of assembling data from around the globe and applying regression analysis approaches to detect patterns and trends.

5. How might this approach be relevant to Bay Delta?

Eutrophication, hypoxia and nutrient loading have not usually been identified among the key issues in the Delta but could become more important if turbidity really is declining. Interestingly, fisheries landings from the San Francisco Bay estuary are among the lowest of any reported large estuary or coastal sea (Denise Breitburg, personal communication). Why is that?

6. Follow up regarding additional questions/literature review/etc?

Another paper on this topic, addressing the question, "How do fisheries and nutrients interact to affect fisheries production, fisheries, and options for fisheries management?" is:

Breitburg, D. L., J. K. Craig, R. S. Fulford, K. A. Rose, W. R. Boynton, D. C. Brady, B. J. Ciotti, R. J. Diaz, K. D. Friedland, J. D. Hagy III, D. R. Hart, A. H. Hines, E. D. Houde, S. E. Kolesar, S. W. Nixon, J. A. Rice, D. H. Secor and T. E. Targett. 2009. Nutrient enrichment and fisheries exploitation: interactive effects on estuarine living resources and their management. Hydrobiologia 629:31-47.

Template for ISB Documentation of Stressors

A. General Information: **Climate Effects on Fish Recruitments**

1. Name or Location of Example/Approach: Chesapeake Bay

2. Literature/Citations Used:

Wood, R. J. 2000. Synoptic scale climate forcing of multispecies fish recruitment patterns in Chesapeake Bay. Ph.D. Dissertation, School of Marine Science, College of William and Mary, Gloucester Pt., VA.

Wood, R. J. and H. M. Austin. 2009. Synchronous multidecadal fish recruitment patterns in Chesapeake Bay, USA. Canadian Journal of Fisheries and Aquatic Sciences 66:496-508.

3. Reviewer(s): Ed Houde

B. Specific Questions:

1. What stressors are considered?

Climate and climate regimes that support opposing late winter – spring conditions (freshwater flow and temperature)

2. Are stressors categorized? If so, how?

Conditions that support multispecies recruitment patterns were categorized in an approach termed "synchronous climatology" that associates regional climate patterns with recruitments of anadromous or shelf-spawning fishes.

3. Are the relations between stressors and management objectives modeled, and if so, how?

Yes. The multispecies patterns are well described by the climatologies and statistical modeling. The authors suggest that the approach is valuable in support of evolving multispecies and ecosystem-based fisheries management.

4. If stressors are prioritized, describe the general approach.

The general approach is to identify recruitment levels in individual species of fish and also the patterns for species groups in principal components analysis, and to link the recruitment success of the groups to predominant climate patterns. Opposing

patterns were found for anadromous species, e.g., striped bass, white perch, shads and river herrings that were favored by cold and wet winter-spring conditions and shelf-spawning species, e.g., spot, summer flounder, menhaden that were favored by warmer and dryer conditions. Two persistent climate regimes, each of at least two decades in duration, with a major shift in 1992, were detected that were associated with the observed multispecies recruitment patterns.

5. How might this approach be relevant to Bay Delta?

The POD and relationships of multispecies variability in reproductive success and recruitment with respect to different climate and freshwater flow regimes might be investigated with this approach. In Chesapeake Bay, the synoptic climatology approach also has been shown to be effective in evaluating variability in primary production and zooplankton production (taxa and levels) in Chesapeake Bay and might have utility in the Bay Delta.

6. Follow up regarding additional questions/literature review/etc?

Related papers:

Kimmel, D. G., W. D. Miller, and M. R. Roman. 2006. Regional scale climate forcing of mesozooplankton dynamics in Chesapeake Bay. Estuaries and Coasts 29:375-387.

Miller, W. D., D. G. Kimmel and L. W. Harding. 2006. Predicting spring discharge of the Susquehanna River from a synoptic climatology for the eastern United States. Water Resources Research 42:1-12.

Template for ISB Documentation of Stressors

A. General Information: Habitat Suitability, Chesapeake Bay, Sturgeon Example

1. Name or Location of Example/Approach: Chesapeake Bay

2. Literature/Citations Used:

Niklitschek, E. J. and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine, Coastal and Shelf Science 64:135-148.

3. Reviewer(s): Ed Houde

B. Specific Questions:

1. What stressors are considered?

Temperature, Low dissolved oxygen, salinity

The authors use bioenergetics modeling approaches to determine what proportion of habitat in Chesapeake Bay is suitable for survival and production of threatened Atlantic sturgeon? (And, by implication, provide a method that could be applied to other fishes or organisms)

2. Are stressors categorized? If so, how?

Yes. Hypoxia and its potential effects are the primary concern being evaluated and modeled. Temperature and salinity are additional factors (stressors).

3. Are the relations between stressors and management objectives modeled, and if so, how?

A multi-factor, spatially-explicit bioenergetics model is developed for young Atlantic sturgeon that evaluates how limiting levels of DO force sturgeon to occupy sub-optimal habitats with respect to temperature and salinity. Potential production is modeled. Management objectives are to protect and restore, if possible, this threatened species. Maps of 'habitat suitability' are produced that show the surprisingly small area of Chesapeake Bay now available to support production of Atlantic sturgeon (inter-annually 0 to 35% of the Bay in summer months). With improved water quality and better DO conditions, more habitat would be available for both Atlantic sturgeon and endangered shortnose sturgeon. The approach can

be, and has been, applied to other fishes in Chesapeake Bay, e.g., striped bass (Costantini et al. 2008), bay anchovy (Ludsin et al. 2009).

4. If stressors are prioritized, describe the general approach.

5. How might this approach be relevant to Bay Delta?

The approach has broad generality to evaluate habitat suitability for organisms. Growth and production potential are modeled and mapped, highlighting critical regions or parts of an ecosystem that are vulnerable to stressors as well as those regions that have high potential productivity for the taxa being modeled. Many driving factors or stressors can be incorporated into the bioenergetics modeling framework. One drawback is that there is a need for knowledge on eco-physiology of organisms and their probable responses to stressors, based on laboratory or other experimental studies, to use this approach effectively.

6. Follow up regarding additional questions/literature review/etc?

Two related references:

Costantini, M. S. A. Ludsin, D. M. Mason, X. Zhang, W. C. Boicourt and S. B. Brandt. 2008. Effect of hypoxia on habitat quality of striped bass (*Morone saxatilis*) in Chesapeake Bay. Canadian Journal of Fisheries and Aquatic Sciences 65:989-1002.

Ludsin, S. A., X. Zhang, S. B. Brandt, M. R. Roman, W. C. Boicourt, D. M. Mason and M. Costantini. 2009. Hypoxia-avoidance by planktivorous fish in Chesapeake Bay: implications for food web interactions and fish recruitment. Journal of Experimental Marine Biology and Ecology 381:S12—S131.